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Assessing Food Production Potentials in the

Final State of Stationary Populations

by

Adolf Weber

Department of Agricultural and Applied Economics

University of Minnesota
Institute of Agriculture, Forestry and Home Economics
St. Paul, Minnesota 55108

How much land does a man need?
Leo Tolstoy 1886

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1. Introduction and Overview

Since Malthus many authors have elaborated the nagging question "How many people can be provided with food on earth?". Thus, the purpose of this study is to explore and examine concepts which try to measure the food production potential of the earth.[1]

Two groups of approaches characterize the literature. The first group derives its conclusions from comparing differing yield levels between countries, areas or agricultural experiment stations. One argues quite reasonably that through the application of modern technologies, low productivity land can be developed to higher yield levels. However, the theoretical maximum of food production is not specifically assessed. This may lead to an underestimation of the earth's food production potential only because observed yield levels are the basis of the assesments made. Pertinent to this approach is that as soon as the extent of the cultivable land, yield, and comsumption levels are determined, the number of people to be nourished on earth can be calculated. Because this approach has an insufficient coverage in space and in time, it will not be considered further.

The second group of approaches is more recent and scholarly conceived. Botanists and agronomists have assessed quantitatively the actual and theoretical performances of the world's various natural vegetation and agricultural production systems. In Section 2 an attempt will be made in presenting the basic concepts with global assessments.

However, the natural scientists' approach is mostly applied to various aggregates of global, continental or agroclimatic zones which disregard national boundaries. This study is designed to transform and adjust global, continental and agroclimatic zones' estimations of the food production potential to country levels. The food production potential of countries is then related to estimations of its stationary population. Various utilization rates of the food production potential are assumed. This permits exploration of the possible food consumption levels in the final state of a country's stationary population.

This study has to rely on many assumptions and generalizations. Some calculations and estimations lack the desirable accuracy. Further, the time horizon appears, compared to current problems of the world food economy, rather distant. But it is hoped that a better understanding of how to evaluate the food production potential of the earth, in the world's regions and countries is the consequence.

2. Assessments of Global Production Potentials

2.1 Approaches in the Natural Sciences

A first attempt of assessing nature's production potential has already been made in 1862 by Liebig when he estimated the size of the primary production of plants on the earth. The next step in quantifying the earth's primary production was taken by botanists. Lieth (4, 5, 6) developed (1972) for the world a complex model of estimating primary productivity (biomass) for the main types of vegetation (forests, savannahs, grassland, cultivated land, etc.). To model nature's production function at various latitudes and locations, an inventory of the world's climate represented the first step. Lieth used data on temperature, precipitation, evaporation of 1,000 metereological stations from all over the world. The results were presented and mapped in terms of dry matter production for the land and the sea. He estimated the earth's annual total dry matter production at 155 X 10^9 tons, of these 55 X 10^9 are produced in the sea and 100 X 10^9 tons on the land.

To get his share of the biomass, man is and has permanently been in competition with other living organisms. Further, only the smaller part of the annual biomass produced is accessible to man and edible. Therefore, man has to use his domesticated animals which convert for him some of the inaccessible fibrous material into edible food. Under several assumptions Lieth estimated the number of people which could be supported by the earth's ecological system at 7 to 15 billion people.

The approach of botanists has its virtues. It emphasizes that primary productivity or biomass production occurs independently of man, but differs in amount according to natural resources available at each location. However, the estimation of the world's total annual biomass production out of broadly defined vegetation systems remains, for the purpose intended, crude and too summary. One can rarely derive the proper share of food out of total biomass production which could be made available to man.

2.2 Approach of Agronomists

An estimation of the earth's food producing potential was undertaken in 1975 by Dutch agronomists of the University of Wageningen in the Netherlands (1). It was part of a project (11) "Food for a Doubling World Population" which was initiated in response to the Club of Rome's world-wide known study "The Limits to Growth."[2]

The theoretical framework of the assessment procedure was developed by the Dutch agronomist De Wit (12). He considered the photosynthetic potential of cultivated plants as a function of location, latitude and an inventory of the world's climate (solar energy, monthly air temperature, precipitation, evatransporation, leaf canopy, etc.). The results were summarized in a table for a standard crop[3] (conceived as a C3 plant). The authors Buringh, van Heemst and Staring (1, p. 27) described the procedure as follows: "indicating for the middle of every month of the year the daily totals of photosynthesis on every clear (PC) and overcast (PO) day of various latitudes. PC and PO can be derived from this table for any location by linear interpolation. These totals, calculated on the basis of the light climate, can only be reached when the average temperature is reasonable. This is presumed to be the case when the average temperature is 10°C or higher."

They used the following apparatus of formula to estimate the mean monthly gross photosynthesis (CAR):

(1) $CAR = ID (F \cdot PO + (1 - F) . PC)$[1] where

CAR = Gross Photosynthesis expressed in kg carbohydrate per month and hectare,

ID = the number of days in the month;

F = the fraction of the time when the sky is overcast and

(2) $F = 1 - h \cdot H^{-1}$ where

h = mean monthly sum of hours of sunshine, local data;

H = the monthly sum of maximum hours of sunshine.

Carbohydrates are transformed into Dry Matter (DM) by multiplying with the factor 0.65 which yields:

(3) $DM = 0.65 \times ID (F \cdot PO + (1 - F) \cdot PC)$.

The formula can only be applied, however, when the average temperature is for more than three months higher than 10°C and is written as:

(4) $DMY = DM \times MO$ where

DMY = Dry Matter production per Year and

MO = Number of Months above 10°C subject to $MO \geq 3$.

The so calculated potential dry matter production contains still the roots, stems, leaves, flowers, and fruits. Under the assumption that the dry matter production is composed as follows: Roots and stubble (25% of DM), straw (37.5% of DM), grain (37.5%

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[1]This formula was later changed into:
(1a) $CAR = ID (F^2 \cdot PO + (1 - F^2) \cdot PC)$ to permit a non-linear interpolation between the two states of the sky (clear or overcast). The formula now takes into account all diffuse radiation and may lead at some locations to higher estimations of food production potentials (9). In this contribution only the original calculations based on formula (1) have been considered.

of DM) with 2% as harvest loss and a moisture content of the grain of 15% the maximum production in grain equivalents is then calculated:

(5) MPGE = DMY x (0.75 X 0.5 X 0.98 / 85) X 100

or MPGE = 0.432 X DMY.

However, the conditions of growing crops are rarely optimal in the world's agricultural regions. Nutrients are missing or the water supply is the limiting factor. A proper soil inventory had to be developed. From the world's soil (and water) inventory, the authors introduced reduction factors for poor soils and for water deficiencies. The basis for applying reduction factors (ranging from 0 to 1) have been maps of 222 broad soil regions of FAO/UNESCO which had a scale of 1:15,000,000. The areas, with respective water deficiencies, were derived from related studies on water availabilities. The lowest of both limiting factors were then applied to reduce the tabulated photosynthetic performance in each of the 222 soil regions.

Pertinent to this approach of estimating the MPGE is the appraisal of the potential agricultural land and an assessment of the potentially irrigable arable land (1, p. 50). The MOIRA elaboration includes further assessments of development cost categories, the distribution of land productivity classes and the topography of soils (lowland, upland, deserts, mountains) in the world's regions. More details can be derived from the source. The final calculation of the MPGE for the world in total can be found in Table 1.

2.3 Global Assessments and Comparisons

Nature has had millions of years time to maximize biomass production on earth. Thus, nature maximizes at each location and climate the sun light's energy by a diversity of plants. The more optimal the growth conditions, the higher is the biomass production and the diversity of contributing plants. This is revealed in the rich variety of plants growing in lushy tropical forests and the very small number of plants and tiny biomass production in the world's deserts and tundras.

However, production targets of nature are not identical with those of man. Man has, compared to nature, at his disposal only a reduced number of cultivated plants which guarantee his survival, because he can not live from tree branches, leafs, ferns, moss, etc. Therefore, man has been forced to increase food production by enlarging his share of cultivated plants in total biomass production.

By converting nature's annual biomass production and the food production (actual and potential) into energy units (Joule [J]), one can compare the respective dimensions of the botanists' and agronomists' approaches (Table 2). In 1964-66 world food production represented only 3.2% of total biomass production. The above assessed food production potential would finally represent 38% of total biomass production on land (12).

2.4 Approaches Developed by FAO/IIASA

The methodology developed by the Wageningen group has been

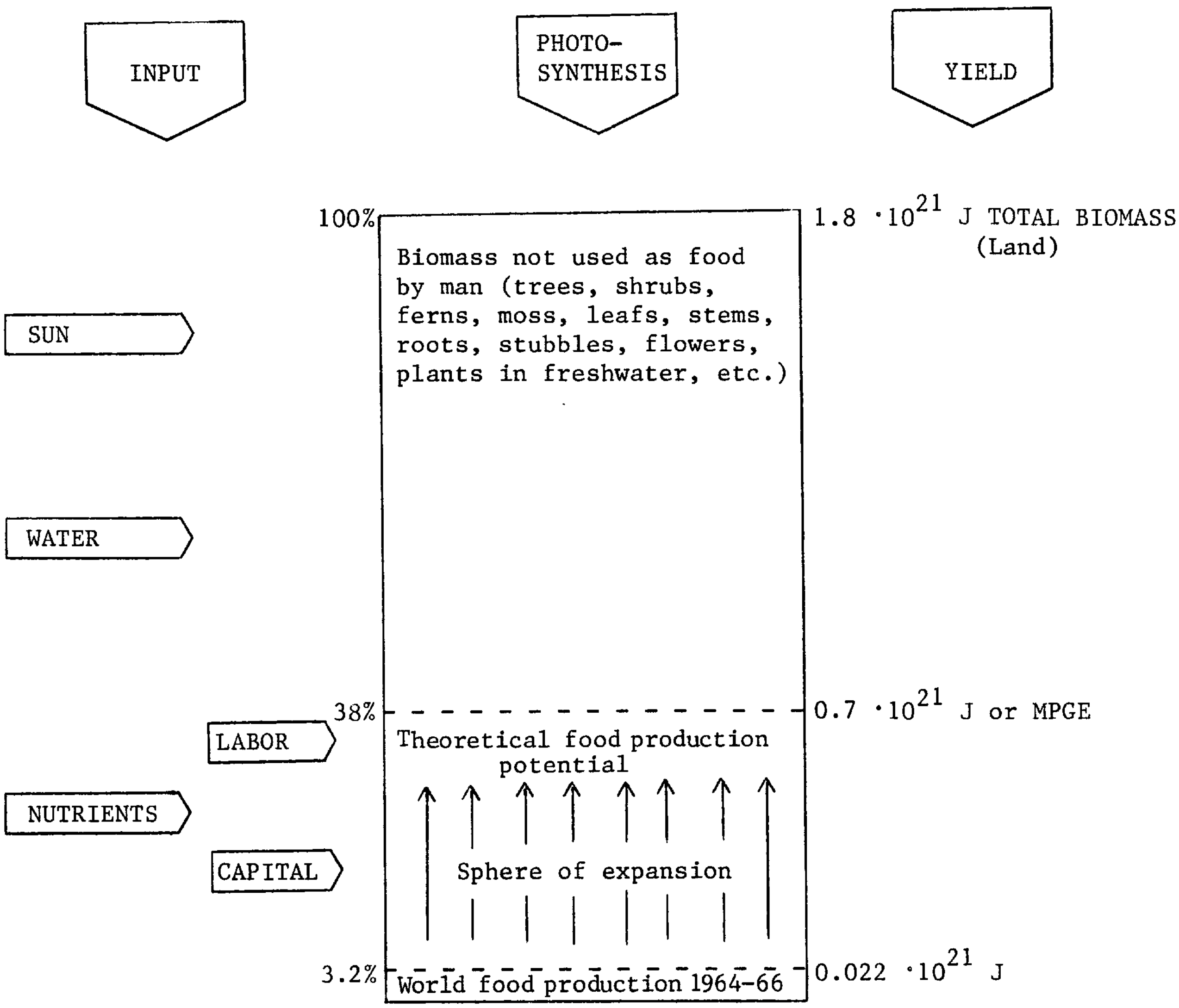
Table 1: The Absolute Maximum Production of Grain Equivalents (MPGE) World, Continents

Region	Arable land[a] 1982	Potential agricultural cropland	MPGE tons/ hectare/ year	MPGE 10^9 t	MPGE in %
	Million Hectares				
South America	139	617	18.0	11.1	22.3
Australia	47	226	10.4	2.3	4.7
Africa	183	762	14.3	10.8	21.8
Asia	506	1,081	13.2	14.3	28.6
North and Central America	273	629	11.3	7.1	14.2
Europe	322	399	10.5	4.2	8.4
World	1,473	3,748	13.4	49.8	100.0

[a] Includes permanent crops. The arable land of the U.S.S.R. has been divided into 182 million hectares for Europe and 50 million to Asia.

Source: MOIRA, p. 25-49. -FAO, Production Yearbook 1983.

Table 2: Estimated Annual Biomass[a] Production on Earth[b] compared with the World Food Production in 1964-66[c] and the World's Absolute Maximum Production in Grain Equivalents (MPGE)[c] in Joule (J)[d]



[a]According to Lieth (1972). [b]Without biomass produced in oceans. [c]MOIRA.

[d]Dry matter production and grain equivalents have been converted into energy units (1 Joule = 0.2388 cal) under-adopting the following conversion ratios: one g of dry matter = 4.23 kcal and one g of grain equivalent = 3.3 kcal.

further pursued by a group of researchers of FAO/IIASA (3, 8). They differ in details of the climatic and soil inventory, e.g. they use for assessing the food producing potential a soil map of larger scale (1:5,000,000 instead of 1:15,000,000). Instead of estimating the production potential in 222 broad soil zones, they consider agroecological cells of 10,000 hectares in each of the 117 developing countries (without China). Instead of a standard crop, they assess the performance of several suitable food crops. Finally, the FAO/IIASA research group distinguishes different levels of inputs (low, medium or high). The intention is to determine those countries which don't even have at the high input level enough food in the year 2000. However, conclusions for the long run are difficult to draw because the high input level is neither quantitatively defined nor is the underlying production function explained.

The FAO/IIASA approach is not followed here despite finer details in soil and climate inventory and the broader range of food crops considered. The FAO/IIASA approach has the disadvantage that it covers only one part of the world. Further, it can not be derived from the study how the various crops were aggregated and which proportion of the food production potential in each agroecological cell should be mobilized by the year 2000 to meet the food requirements.

Similar studies seem to have been undertaken for the U.S.S.R. by Soviet scientists (2, 7). However, the methodology, data and results have, until now, not been accessible to the general public. This is mentioned here only as an indication of how appealing the methods of estimating food production potentials have been.

3. Food Production Potentials or the Theoretical Maximum of Food Production

3.1 Theoretical Yield Potentials in Countries

As mentioned above, the estimation of food production potentials in the MOIRA-Study started from 222 soil zones. The aggregation of grain equivalents was conducted as continental and world totals (Table 1). The disaggregation to country levels is planimetrically done in the following Figures 1 to 6. The appendix contains the elaborated country data in three tables.

The published maps of soil zones in the MOIRA-study had to be disaggregated and allocated to very uneven sized countries. The allocation is easy if a country belongs only to one soil zone. Some countries have extremely rugged national boundaries which hampers planimetric accuracy. Most of the larger countries belong to several soil zones (like Brazil, China, the U.S.A., and U.S.S.R.). Brazil has 16 soil zones, China 13, the U.S.A. has 17, but the U.S.S.R. has 30 different soil zones. To give only one example of the diversity of production conditions in large countries: the highest yield class in the U.S.A. has 22.6 tons of GE per hectare, however, the lowest reaches only a theoretical yield of 5.2 tons. Therefore, in most countries a complex weighting of the various soil zones had to be pursued. To minimize possible differences between MOIRA's continental and the planimetrically derived country results, some, but minor balancing calculations, were applied. Additionally, tiny islands, many small states, the small Levantine countries (Israel, Jordan, Lebanon), countries on the Arabic peninsula (Yemen [North and South], Oman), both Koreas and Switzerland have been excluded. Presently, these countries do not cover more than 1% of the world grain (or food) production.

The MOIRA-Study distinguishes six land productivity classes (Table 3). Forty-five percent of the world's potential agricultural land has theoretical yields of more than 15 tons of grain equivalents. It is concentrated in areas where neither frost nor extended droughts interrupt the year's vegetation period, typical for the lower latitudes in Latin America, Asia and large parts of Africa. The special distribution of six land productivity classes among all continents is revealed in Figure 1. There are a few countries which have a potential of less than five tons GE per hectare (Mongolia, Mali, and Niger) or more than 25 tons GE/hectare (Egypt and Bangladesh). The countries of Europe, Turkey, China, Japan, Argentina and the United States have on the average a theoretical yield potential of up to 15 tons GE per hectare of their partly large territories. Northern countries, Chile and Australia reach only 10 tons GE per hectare whereas many tropical countries can reach more than 15 and 20 tons GE per hectare.

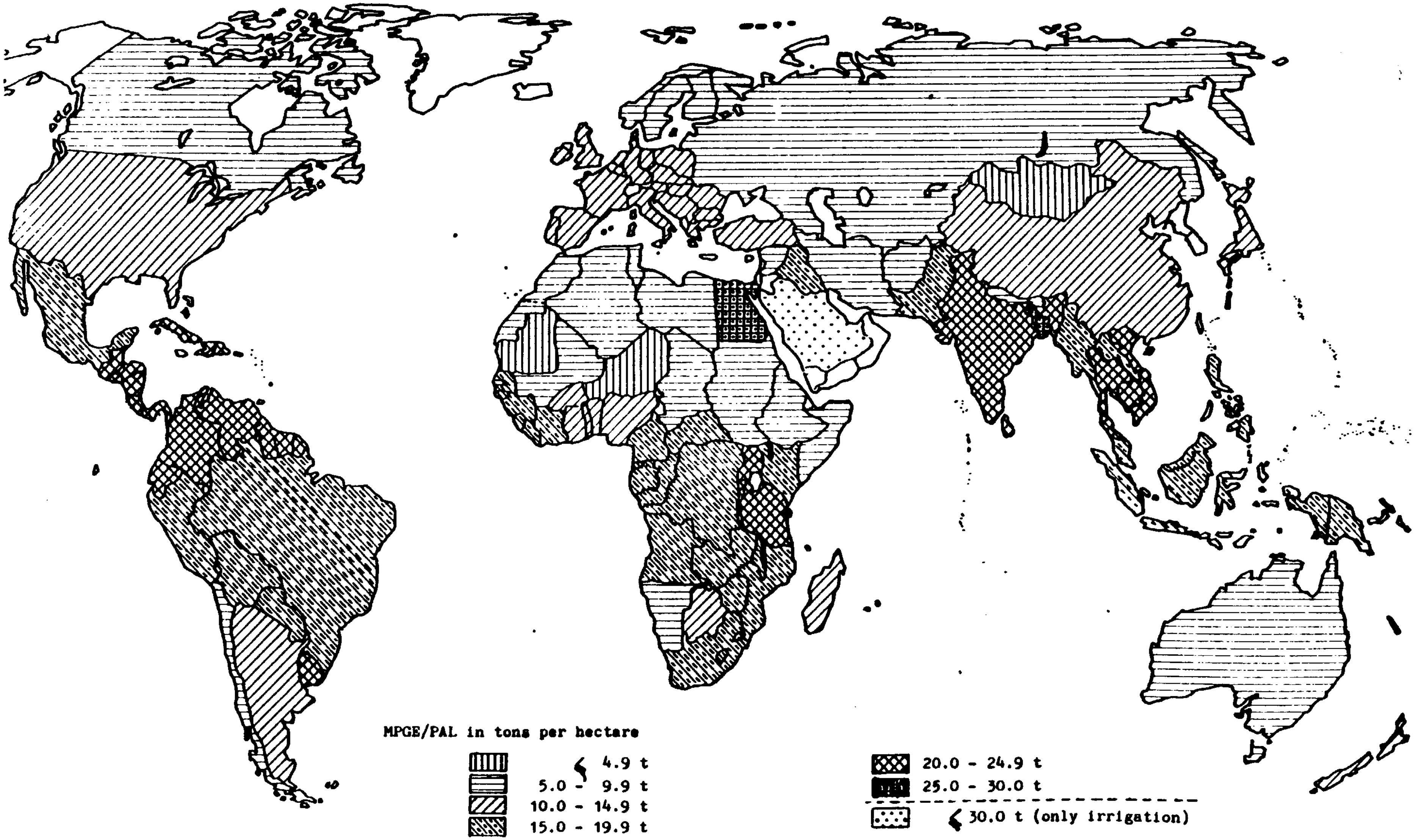
Moreover, it has to be mentioned that the estimations of the food producing potential are based on potential agricultural land

Table 3: Distribution of Soil Productivity Classes in Million Hectares, Maximum Production in Grain Equivalents (GE)

Region	Productivity Class (GE/tons/hectare) in Million Hectares					
	I ≤5	II >5-10	III >10-15	IV >15-20	V >20-25	VI >25
South America	12	--	108	287	185	3
Australia, New Zealand	60	68	26	19	49	--
Africa	93	92	95	335	135	5
Asia	197	51	352	214	135	69
North & Central America	--	342	87	144	48	--
Europe	1	151	224	12	4	--
Total 3,602	362	704	892	1,011	556	77
in %	10	20	25	28	15	2

Source: MOIRA, p. 39.

Figure 1: Maximum Production of Grain Equivalents (MPGE) per Hectare of Potential Agricultural Land (PAL) (Calculated from MOIRA)



-- not on actually cultivated land which is only 40% of the total potential. Thus, one can reasonably assume that the actual crop land use already covers in each country the more fertile soils.

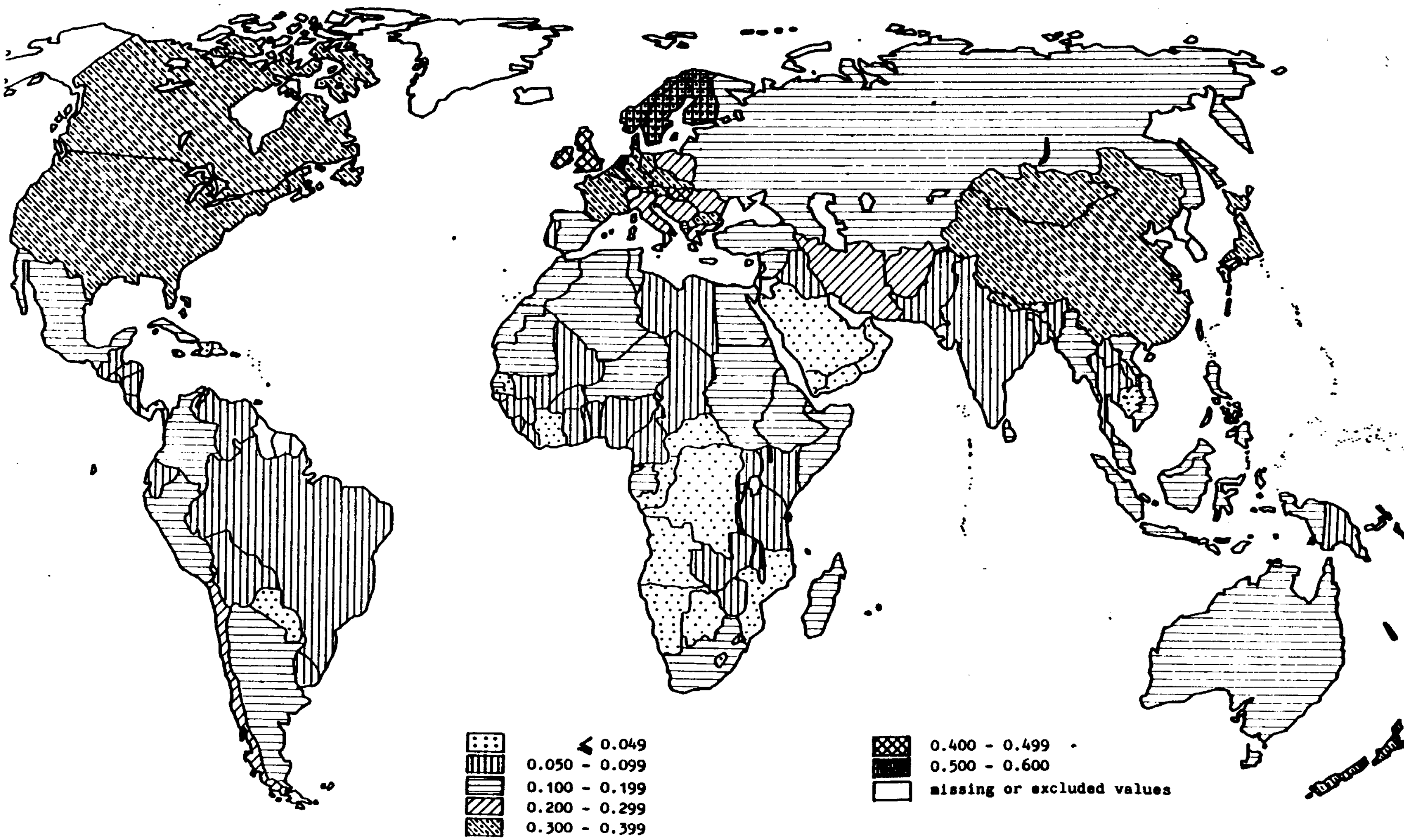
This permits the conclusion that the <u>theoretical</u> yield potential on the actual crop land must be much higher than on the potential crop land.

3.2 Present Grain Yields Versus Potential Yields

More than half of the energy directly consumed by the average man is derived from cereals. One half of all arable land is devoted to the cultivation of grain. Thus, cereals best represent the general agricultural yield level achieved in all countries. The present grain yields have been expressed in Figure 2 as a fraction of the MPGE per hectare of potential agricultural land. According to this calculation only the Scandinavian countries and the Netherlands used in 1981-83 between 50% and 60% of the theoretical yield potential. In most parts of Europe, North America, China, Mongolia and Japan, the present cereal yields reach only between 30% and 40% of the theoretical yield potential. In developing countries -- with few exceptions (Afghanistan, Chile, Iran, Nepal) -- only less than 20% of the theoretical yield potential has been used.

Increases of food production occur by rising yields and expansions of cultivated areas. The still available land reserves differ between continents and among countries. But even in the densely populated countries of Europe (and Nepal) the

Figure 2: Present Grain Yield Levels (1981/1983) as Fraction of the Maximum Production of Grain Equivalents per Hectare of Potential Agricultural Land (MPGE/PAL) (Calculated from MOIRA)



present utilization of the theoretical yield potential is between 30% and 40% in five countries. In most of Europe, the utilization rate of the theoretical potential in Figure 3 is still below 30% and 20%. In North America, China and Japan, the utilization is also below 20% of the potential. The large dotted areas in tropical South America and Africa indicate a large unused potential.

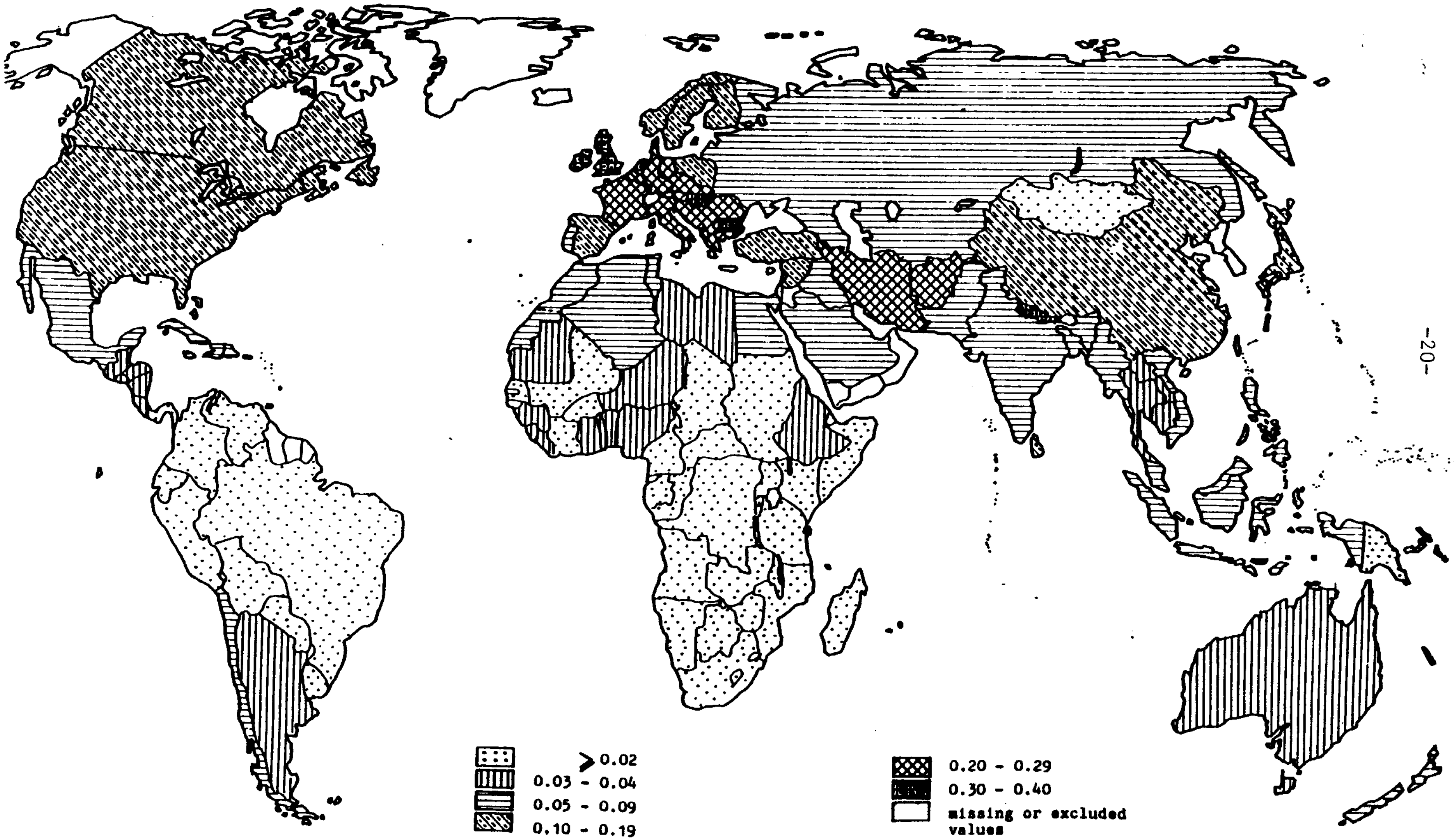
There are two main alternatives in each country to mobilize the food production potential. In some countries it can be done primarily by area expansion, in others mainly by yield increases. Mostly, both alternatives are according to their economic feasibility pursued. The many existing obstacles and the strategies to be followed depend on the specific situation in each country. Generalizations are not very revealing.

The Dutch agronomists have stressed several times in their studies that several technical, political, economic, social and ecological constraints have to be overcome before the theoretical maximum of food production (or parts of it), can be attained. The evidence of these constraints do not call for repetition.

3.3 Food Production Potential in the State of a Stationary World Population

Past experience has shown that as development progresses in education, health, and income levels, fertility and population growth slows down. Thus, recent estimations assume that the human population will not grow indefinitely. Some countries in Central Europe have already reached the state of a stationary

__Figure 3:__ Present Utilization (1981/1983) of the Maximum Production of Grain Equivalents
(Calculated from MOIRA as Present Fraction of MPGE/PAL x Present Fraction of PAL)



population. The World Bank (13) has estimated for every country (excluding countries with a population of less than one million) the hypothetical size of stationary populations in millions of people. The nature of these estimations is described by World Bank as follows: "provide a summary indication of the long-run implications of recent fertility and mortality trends on the basis of highly stylized assumptions" (13, p. 282).

The hypothetical size of the stationary population for the world as a whole is estimated at eleven billion people. The food production potential was estimated at 49.8 billion tons of grain equivalents or 4.52 tons of grain equivalents per capita of the stationary population. The minimum food requirement of the average person can be set at 3,000 kcal per day or 1.095 X 10^6 which corresponds to 332 kg of grain equivalents per year. Therefore, deducting seed and waste, a per capita production of more than 400 kg are unconditionally necessary. However, this level guarantees only the survival and supposes that food is evenly distributed among the population. Taking into account that the income distribution is skewed to the left, 800 kg of grain equivalents would certainly increase safety levels and minimize the extent of malnutrition among the population.

The maximum food which can be used in an affluent society which converts grain, roots, tuber and byproducts of industrial processing into livestock products, alcoholic or non-alcoholic beverages, and feed for all kinds of pets will not be much above two tons GE per capita. The theoretical food production potential is, therefore, with 4.5 tons at least two times above the possible maximum use of food. Utilization rates of 50% and 30% of the food production potential would still yield 2.2 respectively 1.35 tons of grain equivalents per head of the stationary world population. It has to be added that the estimation of the food production potential does not include livestock products from grazing areas or all food from the sea or inland waters.

These global considerations have one big disadvantage. Neither do they take into account the present uneven distribution of food between countries nor do they indicate what the probable future food consumption levels will be in each country.

3.4 Food Consumption Levels in Countries at Stationary Population

Population and income densities per unit of cultivable land determine in each country the state of technologies and the attainable food consumption levels. But population growth and the generation and/or transfer of technical progress does not grow everywhere at the same rate, or grow in the locationally required proportions. Therefore, income and food consumption levels between countries differ enormously. This has been so in the past and there is no convincing reason to assume that food consumption in the final state of a stationary world population would have everywhere the same levels. Therefore, the three utilization rates of the food production potential (10%, 30%, 50%), as described in Section 3.2 and mapped in Figure 3, are used in the sequence of the following assessments.

To better identify those countries where food consumption levels are absolutely insufficient at the final state of a stationary population, six food consumption classes have been built (Figure 4). The lowest two classes ($\leq$ 199, 200-400 kg) represent insufficient food consumption levels, the next two classes (400-599, 600-799) are medium food consumption levels, and all classes above 800 kg GE indicate richer states of food consumption. The dotted areas in Figure 4 are those with a possible per capita production of more than one ton, which permits people to strive for a balanced diet. At the low utilization rate of 10% of the food production potentials all countries in Oceania, most countries of the Americas, but only a few in Africa, Asia or Europe would provide more than one ton of grain equivalents per capita.

The darker shadowed areas characterize those countries where in the final state less than 400 kg or even less than 200 kg GE would be available. In both cases, hunger, undernourishment and malnutrition would prevail. However, if one considers a higher utilization rate of 30% the remaining countries in America (except Salvador) and in Europe are moving out of the more heavily shadowed areas, which represent zones of widespread hunger, undernourishment, and malnutrition (Figure 5). Likewise, as in America and Europe, more countries in Africa and Asia surpass with a 30% utilization rate of the food production potential, the minimum food requirement stipulated above, at 400

Figure 4: Grain Equivalents (GE) available per Capita of Stationary Population
Assumption: 10 % Utilization of MPGE (Calculated from MOIRA)

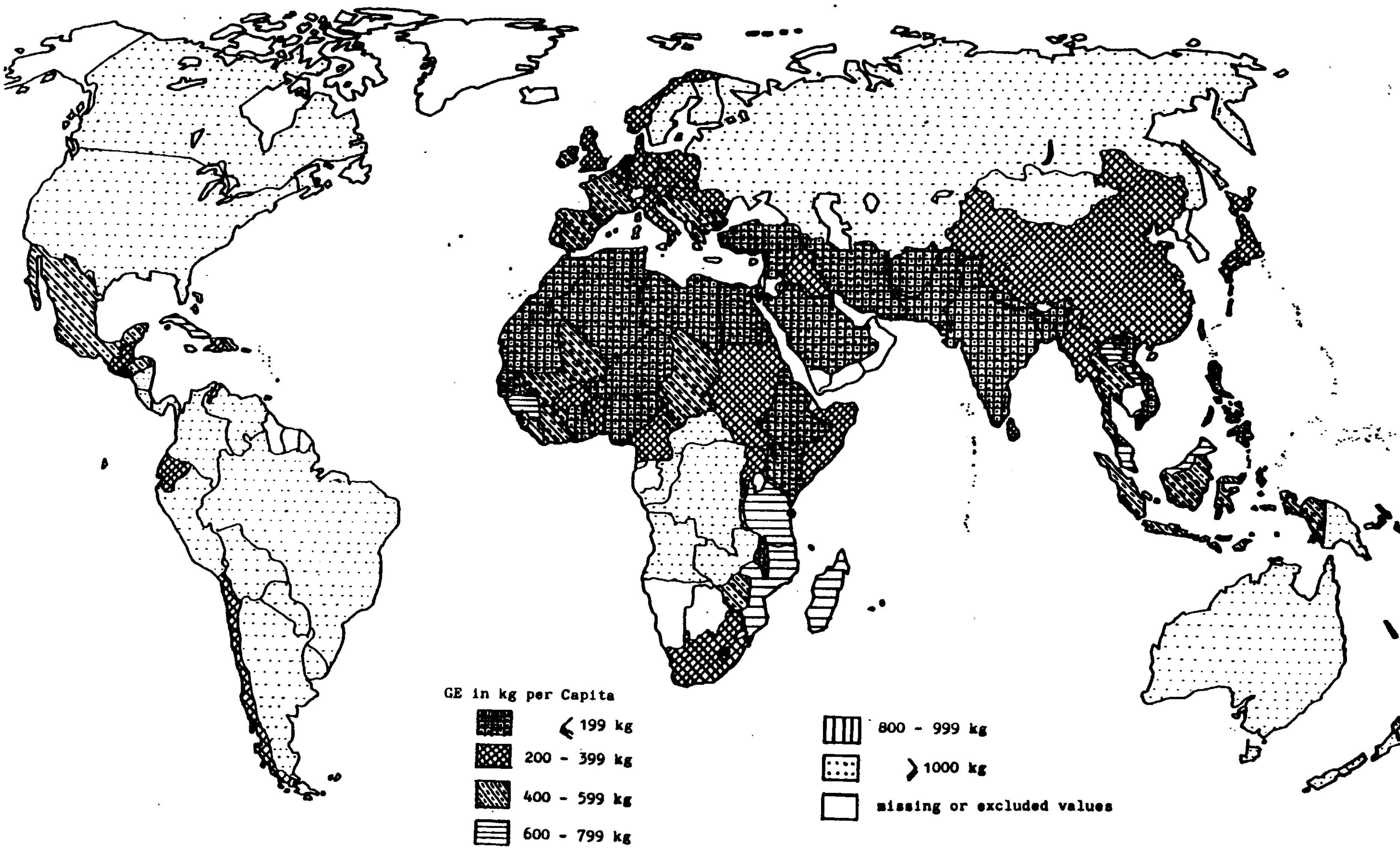
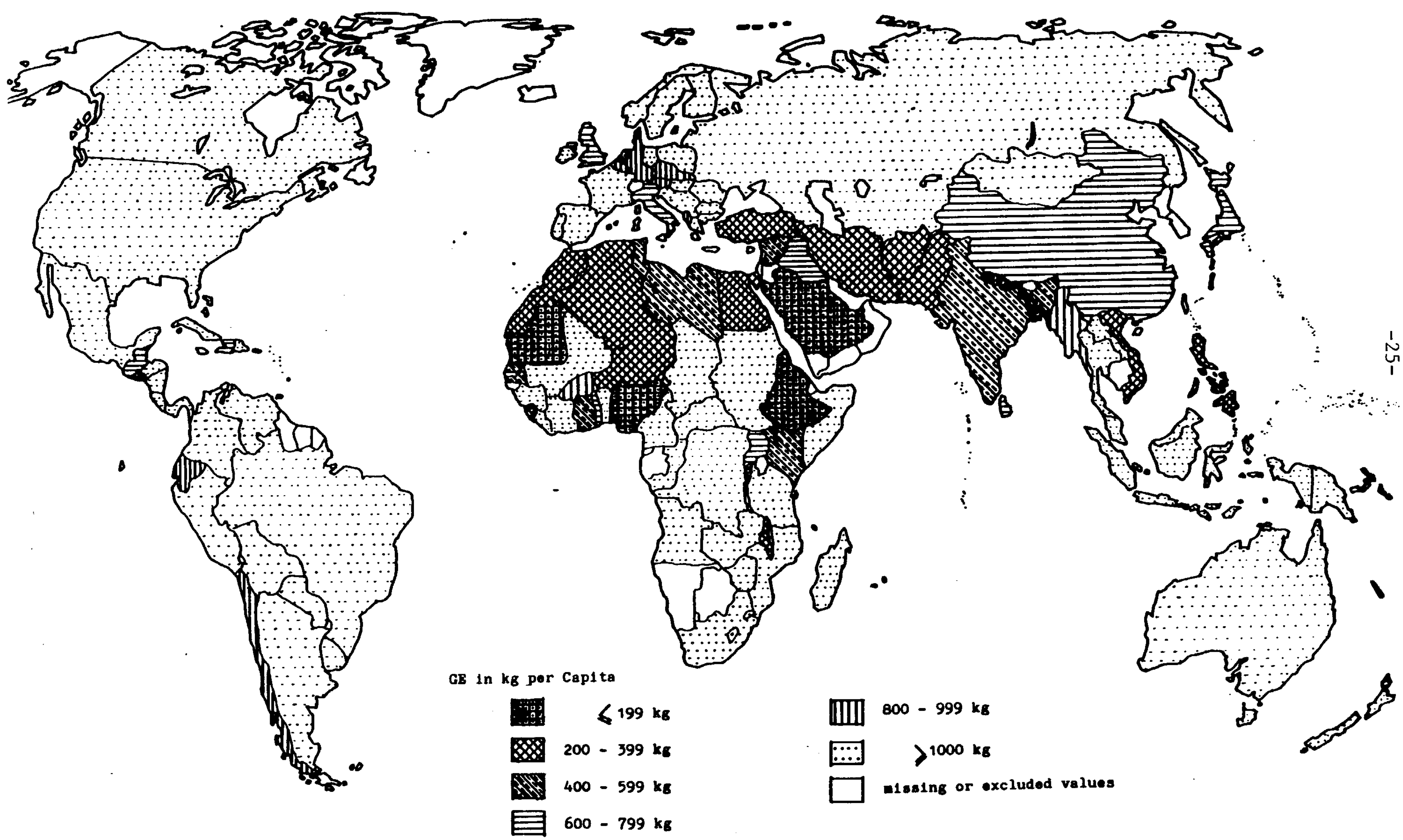


Figure 5: Grain Equivalents (GE) available per Capita of Stationary Population
Assumption: 30 % Utilization of MPGE (Calculated from MOIRA)

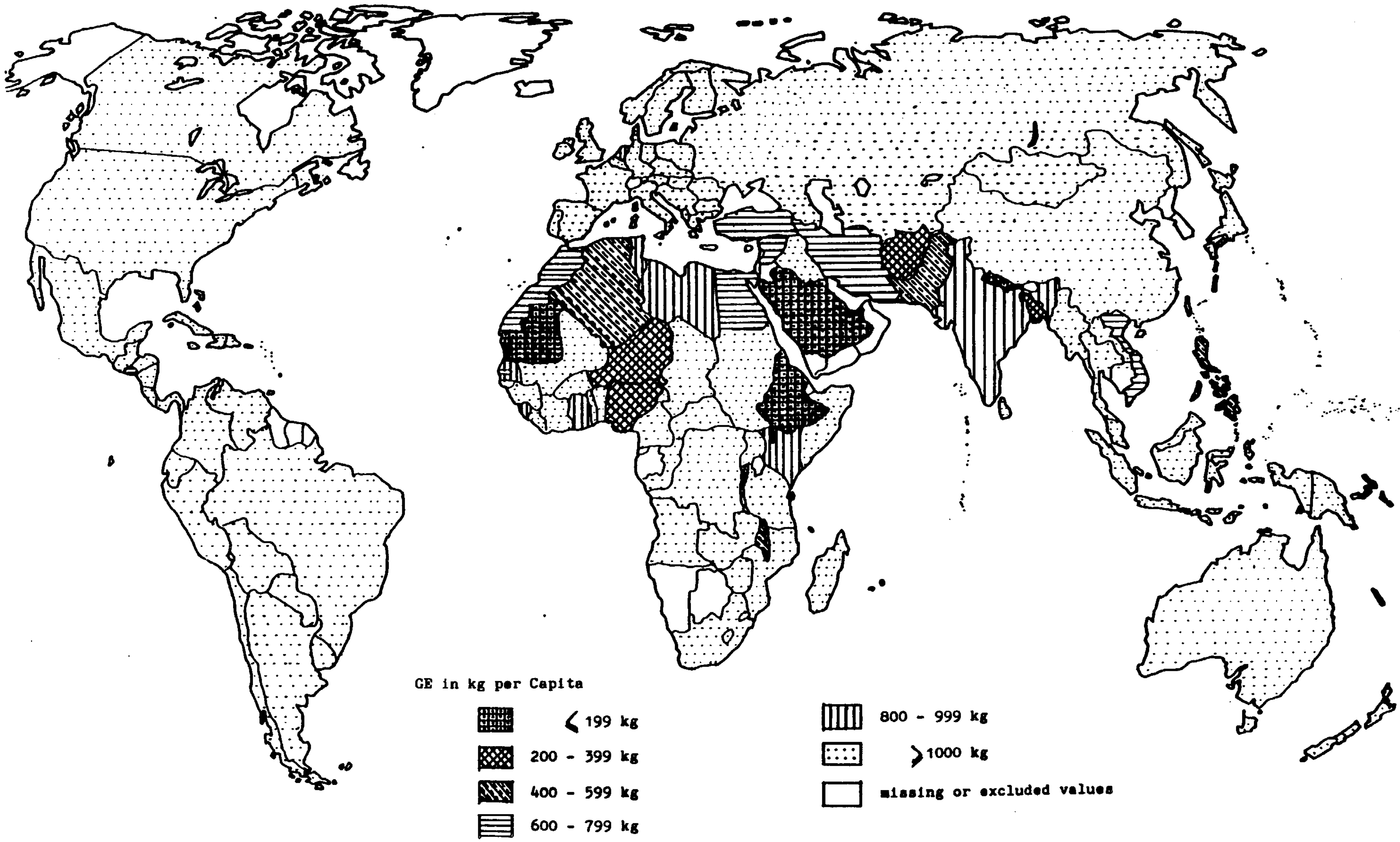


kg GE per person. Europe utilizes, doubtlessly, the highest percentage of its total food production potential (yield potential X area potential). Some countries are already approaching the 40% level (Figure 3). Some countries, with their grain yields, have already surpassed the 50% yield potential (Figure 2). Weighting both factors and their underlying trends, it does not seem entirely unfounded to examine what happens to consumption levels in single countries when one assumes that the utilization of the food production potential is increased to 50% (Figure 6). For three countries of Africa (Rwanda, Ethiopia, and Mauritania) and two in Asia (Nepal and Saudi-Arabia), the food consumption level would not reach 200 kg/GE/capita. Saudi Arabia will certainly have like at present the purchasing power to buy from the international market. In Mauritania and Nepal the not calculated livestock economy based on ruminants plays a large role. Therefore, the net effects would be less than calculated. Less than 400 kg/GE/capita would be available in Afghanistan, Bangladesh, Niger, and Nigeria. The first group of countries embraces 348 millions and the second counts 1,188 millions of the stationary population or 3.2% and 10.8% respectively of the world's total.[4]

Before one tries to assess the present and possible future situation in those countries, one has to be aware that the estimations are based on several assumptions.

1. For the sake of simplifying the calculations, no trade in food and agricultural commodities between surplus and

Figure 6: Grain Equivalents (GE) available per Capita of Stationary Population
Assumption: 50 % Utilization of MPGE (Calculated from MOIRA)



deficit countries has been assumed.

2. The present rigidity of national boundaries prevents large international migrations of agricultural people from taking place. To give an example: From the "overcrowded" Rwanda, people could migrate to neighbouring countries like Tanzania or Zaire which will use, in the final state, a much lower level of their food production potential. Whether larger migrations finally will take place seems at present a very speculative reflection.

3. As the recent experience shows (13), declines of population growth will probably be stronger than the present estimations indicate. The various governments' population policies initiated in the last decade in developing countries will, with high probability, become with some culturally determined delays more effective in the future.

4. The accuracy of the estimations at country levels based on MOIRA's soil and climate inventory should not be overvalued. There may be, in parts of the countries, overestimates as well as underestimates of the food production potential. It is assumed that they cancel each other out.

5. The final state of a stationary world population will occur under present norms of population growth at the end of the next century. However, in most of the developing

countries, this is happening 50 years earlier. That gives ample time to adjust the resources to the requirements in the poorest of the food-deficit countries. However, even after all adjustments have been made, the food consumption levels in the final stationary state of the world population will probably remain uneven as today. But it should be a lesser problem to raise the standards of food consumption in the poorest countries.

4. Conclusion

The present very hypothetical calculations and estimations certainly do not have the state of accuracy one would wish to have. The presented results suggest that the world is not, even in the very long-run, running out of food. The present wisdom permits the conclusion that there will be no unconstrained population growth. Therefore, if man continues to use all his wit and sagacity, he has very good chances to produce all the food he really needs.

Endnotes

[1]The Dutch agronomists framed the food production potential of the earth (or the theoretical maximum of food production) as the (Absolute) Maximum Production of Grain Equivalents (MPGE). If not expressively referred to MOIRA, the three terms are used interchangeably.

[2]In my review of the MOIRA-Study, I tried to deal with both parts of the model (11). Despite the importance of the book, the multidisciplinary approach was obviously a hindrance for broader and deeper reviews in agricultural economic journals. The economists used the agronomic part of the rather complex economic MOIRA-model to examine whether the food production potential would permit to provide people in 106 geographical units (countries) with sufficient food in the year 2009 (1, pp. 306-326). Under the various assumptions of the model the simulated results for aggregated regions showed that in the year 2009 over one billion people would not reach the minimum food standard set at 300 kg grain equivalents per capita unless massive food aid or capital transfers would be initiated.--However, the concern in this study is not the effect of specific policies in a fixed time period for highly aggregated regions. The aim is to assess and to compare for single countries the food production potential with estimated stationary populations. Therefore, our approach is much more modest.

[3]The standard crop is conceived as a C3 plant, "with the properties of a cereal" (1, p. 27). The ratio of straw to grain is calculated at 1:1. It is known that some C4 plants, like sugarcane, have higher photosynthetic performances and are normally grown in the warmer climates. However, the optimal mix of crops at each location will finally be determined by the profitability of and the demand for crops and not by their photosynthetic efficiency. Further, one has to be aware that the conceived "standard crop" is a theoretical concept developed to cover all food crops and all regions of the world. Because of cereals' worldwide importance in cultivation and human food, they are used in this study as an indicator for the various utilization rates of the food production potential or the MPGE.

[4]The listed countries which have probably at a 50% utilization rate of the food production potential insufficient food consumption levels if the present trends persist are also described as critical countries in the FAO/IIASA study (8). This seems to vindicate the planimetric calculations made here.

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APPENDIX

Table 1: Maximum Production of Grain Equivalents (MPGE), Potentials of Agricultural Land and Yields (MOIRA)

COUNTRY	(1) MPGE (10^6t)	(2) PAL (10^6 ha)	(3) MPGE/PAL (t/ha) Min.	(4) Max.	(5) Med.	(6) Number of Regions
Europe						
Norway	15.0	2.5	0.0**	6.7	6.0	3
Sweden	81.4	12.2	5.2	7.9	6.7	3
Finland	52.5	9.6	0.0*	7.2	5.5	4
Denmark	20.9	2.0	10.4	10.4	10.4***	1
Ireland	27.1	2.6	7.3	10.9	10.4	2
United Kingdom	126.3	10.6	7.3	13.6	11.9	3
Netherlands	24.3	1.9	10.4	14.1	12.8	2
Belgium	26.7	2.0	10.4	14.1	13.4	4
France	372.9	27.0	10.0*	23.0	13.8	8
Germany F.R.	148.5	12.2	10.0*	14.1	12.2	5
German D.R.	63.4	6.0	10.4	10.9	10.6	2
Poland	186.6	18.0	7.2	10.9	10.4	5
Czechoslovakia	62.1	5.2	10.0*	14.0	11.9	4
Switzerland	2.1	0.2	10.0*	10.0*	10.0***	1
Austria	26.3	2.0	10.0*	13.4	13.2	4
Hungary	42.6	3.1	12.8	14.0	13.7	2
Portugal	51.7	4.0	10.8	15.3	12.9	3
Spain	272.9	21.3	10.8	14.2	12.8	4
Italy	131.9	10.0	6.7	21.2	13.2	5
Yugoslavia	135.3	10.2	9.2	15.5	13.3	4
Romania	106.1	9.1	8.3	14.0	11.7	6
Albania	16.7	1.1	15.5	15.5	15.5***	1
Bulgaria	57.3	5.2	9.2	12.8	11.0	4
Greece	51.8	3.6	9.2	19.5	14.4	3
U.S.S.R.(Eur. Part)	1917.9	204.2	0.0**	19.5	9.4	14
U.S.S.R.(Asian Part)	2371.5	271.0	0.0**	12.7	8.8	16
U.S.S.R. (Total)	4289.4	475.4	0.0**	19.5	9.0	30
Asia						
Turkey	144.7	11.7	6.8	19.5	12.4	5
Syria	66.6	8.9	6.8	14.7	7.5	3
Iraq	159.7	10.5	6.8	20.8	15.2	4
Saudi Arabia	3.9	0.2	0.0+	30.0++	19.5	1
Iran	201.9	39.5	4.3	11.1	5.1	3
Afghanistan	52.3	10.4	4.3	11.1	5.0	3
Pakistan	402.4	21.9	0.0*	24.2	18.4	6
India	3027.1	138.6	0.0*	29.9	21.8	9
Nepal	3.3	0.6	5.2*	5.2*	5.2***	1
Sri Lanka	66.5	3.0	22.0	22.0	22.0***	1
Bangladesh	255.7	8.5	29.9	29.9	29.9***	1
Mongolia	114.5	35.2	2.0	5.8	3.3	3
China	3377.7	305.1	0.0*	28.7	11.1	13
Burma	361.1	19.9	5.2*	28.7	18.1	3
Lao	140.9	7.9	14.8	21.0	17.8	2
Thailand	510.8	23.5	14.8	28.7	21.7	4
Kampuchea	199.7	9.1	21.0	28.7	21.9	2
Vietnam	222.6	11.0	14.8	28.7	20.2	4
Korea (Rep.)	4.0	0.4	10.7*	10.7*	10.7***	1
Korea Peoples Rep.)	6.9	0.6	10.7*	10.7*	10.7***	1
Japan	298.0	20.8	14.3	14.3	14.3***	1
Malaysia	248.0	14.3	17.3	17.3	17.3***	1
Philippines	134.2	8.0	16.8	16.8	16.8***	1
Indonesia	1818.9	93.2	16.8	25.2	19.5	4

Table 1 (continued)

COUNTRY	(1) MPGE (10^6t)	(2) PAL (10^6 ha)	(3) MPGE/PAL (t/ha) Min.	(4) Max.	(5) Med.	(6) Number of Regions
Africa						
Morocco	86.6	13.9	0.0**	9.7	6.2	3
Algeria	95.6	18.1	0.0**	9.7	5.3	4
Tunesia	35.3	4.8	0.0**	9.7	7.4	4
Libya	36.8	5.2	0.0**	7.0	7.0	2
Egypt	133.0	4.9	0.0**	28.0	28.0	2
Mauritania	2.7	0.8	0.0**	3.3	3.3	2
Senegal	58.3	3.5	0.0**	16.9	16.9	2
Mali	208.0	22.7	0.0**	19.7	9.2	4
Burkina Faso	116.1	10.8	0.4	11.0	10.8	2
Chad	103.4	19.1	0.0**	16.4	5.4	4
Sudan	417.3	70.1	0.0**	21.5	6.0	7
Niger	301.5	12.7	0.0**	11.0	2.4	3
Guinea	210.1	11.8	11.0	19.7	17.8	3
Sierra Leone	30.9	1.8	16.9	16.9	16.9***	1
Liberia	58.3	3.5	16.9	16.9	16.9***	1
Ivory Coast	303.0	15.7	11.0	19.7	19.3	3
Ghana	146.4	10.2	11.0	19.7	14.4	4
Togo	36.2	2.9	11.0	16.4	12.5	2
Benin	52.7	4.4	11.0	16.4	12.0	2
Nigeria	412.7	33.9	0.4	17.6	12.2	4
Cameroon	222.9	14.7	11.0	17.6	15.2	3
Centr. Afr. Rep.	314.7	19.9	11.0	16.4	15.8	2
Gabon	162.3	9.7	16.4	17.6	16.7	3
Congo	251.8	13.9	16.4	25.5	18.1	5
Zaire	1837.0	98.0	16.4	25.5	18.7	8
Ethiopia	91.7	10.7	0.0**	17.2*	8.6	5
Somalia	86.7	12.2	0.0**	14.7	7.1	3
Uganda	196.4	9.1	21.5	21.5	21.5***	1
Kenya	267.3	14.3	0.0**	21.5	18.8	3
Rwanda	24.5	1.1	21.5	21.5	21.5***	1
Burundi	24.5	1.1	21.5	21.5	21.5***	1
Tanzania	806.0	37.9	14.7	21.5	21.3	2
Angola	995.8	61.0	3.1	20.7	16.3	6
Zambia	713.0	37.4	17.3	20.7	19.1	3
Malawi	48.0	2.7	17.6	17.6	17.6***	1
Mozambique	632.7	33.2	17.6	20.7	19.1	3
Namibia	133.7	14.4	0.0**	17.3	9.4	4
Botswana	251.9	21.3	3.9	19.8	11.8	3
Zimbabwe	268.6	14.8	17.3	20.7	18.1	4
Swaziland	18.3	0.9	19.8	19.8	19.8***	1
Lesotho	32.0	1.6	19.8	19.8	19.8***	1
South Africa	480.6	32.1	3.1*	19.8	15.0	4
Madagascar	335.0	25.2	9.0	17.7	13.3	2
North and Central America						
Canada	1218.2	173.5	0.0**	8.8	7.0	8
U.S.A.	4292.5	371.6	5.2	22.6	11.6	17
Mexico	839.1	53.6	5.2	21.2	15.7	10
Guatemala	60.8	2.7	21.2	24.6	22.5	3
El Salvador	21.2	0.9	24.6	24.6	24.6***	1
Honduras	93.2	3.9	23.8*	24.6	23.9	3
Nicaragua	134.5	5.5	23.8*	24.6	24.5	2
Costa Rica	74.3	3.0	24.6	24.6	24.6***	1
Panama	100.9	4.1	24.6	24.6	24.6***	1
Cuba	92.3	4.4	21.2	21.2	21.2***	1
Haiti	31.9	1.3	24.6	24.6	24.6***	1
Dom. Rep.	79.6	3.3	24.6	24.6	24.6***	1
Jamaica	10.7	0.4	24.6	24.6	24.6***	1

Table 1 (continued)

COUNTRY	(1) MPGE (10^6t)	(2) PAL (10^6 ha)	(3) MPGE/PAL (t/ha) Min.	(4) Max.	(5) Med.	(6) Number of Regions
South America						
Venezuela	640.1	29.2	17.1	24.2	21.9	4
Guyana	141.0	6.6	17.1	24.4	21.4	3
French Guyana	39.6	1.9	17.1	24.4	20.8	2
Suriname	93.2	4.4	17.1	24.4	21.2	2
Columbia	905.0	38.5	18.7*	24.7	23.5	6
Ecuador	75.8	3.2	3.0*	24.7	23.7	5
Peru	550.4	30.7	1.0*	23.5*	17.9	6
Bolivia	562.8	33.2	1.0*	23.5*	17.0	9
Paraguay	293.2	18.0	11.4	20.7	16.3	6
Brazil	6534.8	348.3	12.6	25.6	18.8	16
Argentina	1095.5	90.1	2.0*	19.2	12.2	9
Chile	59.7	6.2	1.0*	13.4*	9.6	4
Uruguay	114.6	4.6	24.8	25.6	24.9	2
Oceania						
Australia	1942.0	201.3	0.0**	21.3	9.6	19
Papua New Guinea	284.4	16.9	16.8	16.8	16.8***	1
New Zealand	139.0	10.7	1.3*	16.6	13.0	4
Fiji						
Solomon Is.						
New Caledonia	277.0	13.7	20.2	20.2	20.2***	1
Vanuatu						
World	49918	3714	0.0**	30.0++	13.4	222

* Region C (High Mountain)
** Region D (Desert, Tundra)
— The planimetrically derived values are strongly distorted because the share of arable land is very small.

*** Minimax=Maximax, because only one region, in some cases small deviation from average MPGE/PAL
\+ without Irrigation
\++ only with Irrigation

Source: MOIRA. - Own calculation.

Table 2: Present Grain Yield Levels (1981/83) as Fraction of the Maximum Production of Grain Equivalents per Hectare of Potential Agricultural Land (MPGE/PAL)

COUNTRY	(1) Grain-yield (kg)	(2) in % of yield-potential	(3) Arable land (1000 ha) a)	(4) in % of land-potential	(5) in % of total potential
Europe					
Norway	3606	0.60	840	0.34	0.20
Sweden	3798	0.57	2982	0.24	0.14
Finland	2723	0.50	2368	0.25	0.13
Denmark	4121	0.40	2645	1.00**	0.40
Ireland	4986	0.48	972	0.37	0.18
United Kingdom	5263	0.44	6992	0.66	0.29
Netherlands	6355	0.50	862	0.45	0.23
Belgium	5141	0.38	831	0.42	0.16
France	4862	0.35	18766	0.70	0.35
Germany F.R.	4623	0.38	7466	0.61	0.23
German D.R.	3834	0.36	5008	0.83	0.29
Poland	2611	0.25	14829	0.82	0.21
Czechoslovakia	4072	0.34	5170	0.99	0.34
Switzerland	5100	0.51	412	1.00**	0.51
Austria	4558	0.35	1583	0.79	0.28
Hungary	4839	0.35	5305	1.00**	0.35
Portugal	962	0.07	3550	1.00**	0.07
Spain	1773	0.14	20498	0.96	0.13
Italy	3607	0.27	12323	1.00**	0.27
Yugoslavia	3846	0.29	7838	0.77	0.22
Romania	3178	0.27	10532	1.00**	0.27
Albania	2754	0.18	708	0.64	0.12
Bulgaria	4144	0.38	4153	0.80	0.30
Greece	3162	0.22	3962	1.00**	0.22
U.S.S.R.	1448	0.15	232282	0.49	0.07
Asia					
Turkey	1915	0.15	27452	1.00**	0.15
Syria	1039	0.14	5683	0.64	0.09
Iraq	911	0.06	5450	0.52	0.03
Saudi Arabia	1407	0.07	1129	1.00**	0.07
Iran	1207	0.24	13700	0.35	0.08
Afghanistan	1341	0.27	8054	0.77	0.21
Pakistan	1664	0.09	20410	0.93	0.08
India	1435	0.07	168370	1.00**	0.07
Nepal	1687	0.32	2331	1.00**	0.32
Sri Lanka	2429	0.16	2171	0.72	0.12
Bangladesh	2001	0.07	9133	1.00**	0.07
Mongolia	1036	0.31	1262	0.04	0.01
China	3399	0.31	100897	0.33	0.10
Burma	2891	0.16	10068	0.51	0.08
Lao	1495	0.08	888	0.11	0.01
Thailand	1960	0.09	19026	0.12	0.01
Kampuchea	900	0.04	3046	0.33	0.01
Vietnam	2332	0.12	7105	0.65	0.08
Japan	5300	0.37	4830	0.23	0.09
Malaysia	2857	0.17	4338	0.30	0.05
Philippines	1699	0.10	11180	1.00**	0.10
Indonesia	3165	0.16	19930	0.21	0.03

Table 2 (continued)

COUNTRY	(1) Grain-yield (kg)	(2) in % of yield-potential	(3) Arable land (1000 ha) a)	(4) in % of land-potential	(5) in % of total potential
Africa					
Morocco	941	0.15	8394	0.60	0.09
Algeria	596	0.11	7509	0.41	0.05
Tunesia	882	0.12	4681	0.98	0.12
Libya	432	0.06	2091	0.40	0.02
Egypt	4254	0.15	2470	0.50	0.08
Mauritania	423	0.13	195	0.24	0.03
Senegal	625	0.04	5225	1.00**	0.04
Mali	576	0.06	2053	0.09	0.01
Burkina Faso	541	0.05	2633	0.24	0.01
Chad	422	0.08	3150	0.16	0.01
Sudan	603	0.10	12448	0.18	0.02
Niger	408	0.17	3560	0.28	0.05
Guinea	867	0.05	1574	0.13	0.01
Sierra Leone	1397	0.08	1769	0.98	0.08
Liberia	1206	0.07	371	0.11	0.01
Ivory Coast	672	0.03	3958	0.25	0.01
Ghana	799	0.06	2765	0.27	0.02
Togo	875	0.07	1426	0.49	0.03
Benin	621	0.05	1802	0.41	0.02
Nigeria	696	0.06	30410	0.90	0.05
Cameroon	835	0.05	6950	0.47	0.02
Centr. Afr. Rep.	538	0.03	1958	0.10	0.01+
Gabon	1593	0.10	452	0.05	0.01
Congo	539	0.03	672	0.05	0.01+
Zaire	822	0.04	6406	0.07	0.01+
Ethiopia	1280	0.15	13930	1.00**	0.15
Somalia	681	0.10	1066	0.09	0.01
Uganda	1565	0.07	6030	0.66	0.05
Kenya	1460	0.08	2310	0.16	0.01
Rwanda	1135	0.05	1010	0.92	0.05
Burundi	1175	0.05	1306	1.00**	0.05
Tanzania	1147	0.05	5190	0.14	0.01
Angola	474	0.03	3500	0.06	0.01+
Zambia	1706	0.09	5158	0.14	0.01
Malawi	1165	0.07	2332	0.86	0.06
Mozambique	478	0.03	3080	0.09	0.01+
Namibia	378	0.04	660	0.05	0.01+
Botswana	192	0.02	1360	0.06	0.01+
Zimbabwe	1157	0.06	2680	0.18	0.01
Swaziland	1193	0.06	139	0.15	0.01
Lesotho	840	0.04	298	0.19	0.01
South Africa	1608	0.11	13620	0.42	0.05
Madagascar	1648	0.12	3006	0.12	0.01

Table 2: (continued)

COUNTRY	(1) Grain-yield (kg)	(2) in % of yield-potential	(3) Arable land (1000 ha) a)	(4) in % of land-potential	(5) in % of total potential
North and Central America					
Canada	2351	0.34	46201	0.27	0.09
U.S.A.	4076	0.35	190270	0.51	0.18
Mexico	2272	0.14	23525	0.44	0.06
Guatemala	1459	0.07	1786	0.66	0.05
El Salvador	1558	0.06	725	0.81	0.05
Honduras	1398	0.06	1767	0.45	0.03
Nicaragua	1719	0.07	1262	0.23	0.02
Costa Rica	2079	0.08	626	0.21	0.02
Panama	1009	0.04	582	0.07	0.01+
Cuba	2336	0.11	3213	0.73	0.08
Haiti	965	0.04	897	0.69	0.03
Dom. Rep.	3579	0.15	1442	0.44	0.07
Jamaica	1527	0.06	267	0.67	0.04
South America					
Venezuela	2015	0.09	3757	0.13	0.01
Columbia	2477	0.11	5676	0.15	0.02
Ecuador	1793	0.08	2512	0.79	0.06
Peru	2156	0.12	3516	0.11	0.01
Bolivia	1203	0.07	3375	0.10	0.01
Paraguay	1358	0.03	1940	0.11	0.01+
Brazil	1593	0.08	73985	0.21	0.02
Argentina	2353	0.19	35450	0.39	0.07
Chile	2149	0.22	5528	0.89	0.20
Uruguay	1813	0.07	1448	0.31	0.02
Oceania					
Australia	1280	0.13	44878	0.22	0.03
Papua New Guinea	1442	0.09	372	0.02	0.01
New Zealand	4573	0.35	461	0.04	0.01

** Calculated share of utilisation of potential land is higher than 1; therefore correction to maximum share 1.00.
+ smaller than 0.005.
a) including permanent cultures.

Source: MOIRA. - FAO Production Yearbook Vol. 38, Rome 1984. Own calculations.

Table 3: Grain Equivalents (GE) Available per Capita of Stationary Population at Various Utilization Rates of the Food Production Potential

COUNTRY	(1) Stationary population (Mill.)	(2) MPGE/Capita/kg of stationary population (100%)	(3) kg GE per capita 10%MPGE	(4) kg GE per capita 30%MPGE	(5) kg GE per capita 50%MPGE
Europe					
Norway	4	3750	375	1125	1875
Sweden	8	10125	1013	3038	5063
Finland	5	10600	1060	3180	5300
Denmark	5	4200	420	1260	2100
Ireland	6	4500	450	1350	2250
United Kingdom	59	2136	214	641	1068
Netherlands	15	1600	160	480	800
Belgium	10	2700	270	810	1350
France	62	5210	521	1563	2605
Germany F.R.	54	2759	276	828	1380
German D.R.	18	3500	350	1050	1750
Poland	49	3816	382	1145	1908
Czechoslovakia	20	3100	310	930	1550
Austria	8	3250	325	975	1625
Hungary	12	3583	358	1075	2866
Portugal	14	3714	371	1114	1857
Spain	51	5353	535	1606	2677
Italy	57	2315	232	695	1158
Yugoslavia	29	4655	466	1397	2328
Romania	31	3419	342	1026	1710
Albania	6	2833	283	850	1417
Bulgaria	10	5700	570	1710	2850
Greece	12	4333	433	1300	2167
U.S.S.R.	377	11377	1138	3412	5688
Asia					
Turkey	111	1306	131	392	653
Syria	42	1595	160	479	798
Iraq	68	2353	235	706	1177
Saudi Arabia	62	65	7	20	33
Iran	159	1270	127	381	635
Afghanistan	76	684	68	205	342
Pakistan	377	1066	107	320	532
India	1707	1773	177	532	887
Nepal	71	42	4	13	21
Sri Lanka	32	2094	209	628	1047
Bangladesh	454	564	56	169	282
Mongolia	5	23000	2300	6900	11500
China	1461	2312	231	694	1156
Burma	115	3139	314	942	1570
Lao	19	7421	742	2226	3711
Thailand	111	4604	460	1381	2302
Vietnam	171	1304	130	391	652
Japan	128	2328	233	698	1164
Malaysia	33	7515	752	2255	3758
Philippines	127	1055	106	317	528
Indonesia	370	4916	492	1475	2458

Table 3: (continued)

COUNTRY	(1) Stationary population (Mill.)	(2) MPGE/Capita/kg of stationary population (100%)	(3) kg GE per capita 10%MPGE	(4) kg GE per capita 30%MPGE	(5) kg GE per capita 50%MPGE
Africa					
Morocco	70	1243	124	373	621
Algeria	119	807	81	242	403
Tunisia	19	1842	184	553	921
Libya	21	1762	176	529	881
Egypt	114	1202	120	360	601
Mauritania	8	375	38	113	188
Senegal	36	1611	161	483	806
Mali	42	4976	498	1493	2488
Burkina Faso	35	3314	331	994	1657
Chad	22	4682	468	1405	2341
Sudan	112	3723	372	1117	1862
Niger	40	775	78	233	388
Guinea	28	7500	750	2250	3750
Sierra Leone	16	1938	194	581	969
Liberia	12	4833	483	1450	2417
Ivory Coast	58	5224	522	1567	2612
Ghana	83	1759	176	528	880
Togo	17	2118	212	635	1059
Benin	23	3609	361	1083	1804
Nigeria	618	668	67	200	334
Cameroon	65	3431	343	1029	1715
Centr. Afr. Rep.	13	24231	2423	7269	12115
Congo	10	25200	2520	7560	12600
Zaire	172	10680	1068	3204	5340
Ethiopia	231	398	40	119	199
Somalia	23	3783	378	1135	1891
Uganda	89	2202	220	661	1101
Kenya	153	1745	175	524	873
Rwanda	47	532	53	160	266
Burundi	27	926	93	278	463
Tanzania	117	6889	689	2067	3444
Angola	44	22636	2264	6791	11318
Zambia	37	19270	1927	5781	9635
Malawi	48	1000	100	300	500
Mozambique	82	7720	772	2316	3860
Zimbabwe	62	4339	434	1302	2169
Lesotho	7	4571	457	1371	2280
South Africa	123	3910	391	1173	1955
Madagascar	54	6204	620	1861	3102

Table 3: (continued)

COUNTRY	(1) Stationary population (Mill.)	(2) MPGE/Capita/kg of stationary population (100%)	(3) kg GE per capita 10%MPGE	(4) kg GE per capita 30%MPGE	(5) kg GE per capita 50%MPGE
North and Central America					
Canada	33	36909	3691	11072	18454
U.S.A	292	14702	1470	4411	7351
Mexico	199	4216	422	1265	2109
Guatemala	25	2440	244	732	1220
El Salvador	17	1235	124	371	618
Honduras	17	5471	547	1641	2735
Nicaragua	12	11250	1125	3375	5625
Costa Rica	5	14800	1480	4440	7400
Panama	4	25250	2525	7575	12625
Cuba	15	6133	613	1840	3067
Haiti	14	2286	229	686	1143
Dom. Rep.	15	5333	533	1600	2667
Jamaica	4	2750	275	825	1375
South America					
Venezuela	46	13913	1391	4174	6956
Columbia	62	14597	1460	4379	7298
Ecuador	27	2815	282	844	1407
Peru	49	11224	1122	3367	5612
Bolivia	22	25591	2559	7677	12795
Paraguay	8	36625	3663	10988	18313
Brazil	304	21496	2150	6449	10748
Argentina	54	20296	2030	6089	10148
Chile	21	2857	286	857	1429
Uruguay	4	28750	2875	8625	14375
Oceania					
Australia	21	92476	9248	27743	46623
Papua New Guinea	10	28400	2840	8520	14200
New Zealand	4	34750	3475	10425	17375

Source: MOIRA.- World Bank, World Development Report 1984.-
Own calculations.

Table 4: The Hypothetical Size of the Stationary Population

Country Categories	Millions
Low income countries	5,863
Middle income countries	2,397
Upper-middle income coutries	1,338
High income oil exporters	96
Industrial market economies	828
East European nonmarket economies	523
World	11,039

Source: World Bank, World Development Report 1984.